

# Parton rescattering effect on the charged hadron forward-backward multiplicity correlation in $pp$ collisions at $\sqrt{s}=200$ GeV

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The parton rescattering effect on the charged hadron forward-backward multiplicity correlation in  $pp$  collisions at  $\sqrt{s}=200$  GeV is studied by a parton and hadron cascade model, PACIAE, based on the PYTHIA model. The calculated multiplicity and pseudorapidity distribution of the final state charged hadron are well compared with experimental data. It turned out that the final state charged hadron pseudorapidity distribution are different from the initial state charged partons. The parton rescattering effect on the charged hadron forward-backward multiplicity correlation increases with increasing parton rescattering strength in the center pseudorapidity region ( $|\eta| < 1$ ). However, this effect becomes weaker in the outer pseudorapidity region ( $|\eta| > 1$ ).

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## I. INTRODUCTION

The study of fluctuations and correlations has been suggested as a useful means to reveal the mechanism of particle production and the formation of Quark-Gluon Plasma (QGP) in the relativistic heavy-ion collisions [1, 2]. Correlations and fluctuations of the thermodynamic quantities and/or the produced particle distributions could be significantly altered when the system undergoes phase transition because the degrees of freedom is largely different between the hadronic matter and the quark-gluon matter.

The experimental study of fluctuations and correlations becomes a hot topic in relativistic heavy ion collisions with the availability of high multiplicity event-by-event measurements at the CERN-SPS and BNL-RHIC experiments. An abundant experimental data have been reported [3, 4, 5, 6, 7, 8, 9, 10, 11] where a lot of new physics are arisen and urgent to be studied.

A lot of theoretical investigations have also been reported such as Refs. [12, 13, 14, 15, 16]. We have used the PYTHIA model to investigate the strength of charged hadron forward-backward multiplicity correlation in  $\bar{p}p$  and  $pp$  collisions at  $\sqrt{s}=200$  GeV [16]. It argued that a factor of 3-4 apparent discrepancy between UA5  $\bar{p}p$  data [17] and STAR  $pp$  data [18] can be attributed to the differences in detector acceptances and observed bin interval in both experiments. In [15] the back-to-back parton scattering was considered as the origin of final state hadronic covariance. They assumed the details of hadronization are not essential and related the back-to-back parton scattering angles to a Gaussian-like hadronization function. Then they derived the final state charged hadron forward-backward multiplicity

covariance. Without more dynamical inputs, their results were well compared with STAR data [18], “thus dispelling the notion that correlation length has any fundamental significance”. Stimulated by this interesting conclusion, a parton and hadron transport model, PACIAE [19], is employed in this paper to investigate the effect of parton rescattering in parton evolution stage on the final state charged hadron forward-backward multiplicity correlation in the  $pp$  collisions at  $\sqrt{s}=200$  GeV.

Following [20] the strength of charged particle forward-backward multiplicity correlation,  $b$ , is defined as

$$b = \frac{\langle n_f n_b \rangle - \langle n_f \rangle \langle n_b \rangle}{\langle n_f^2 \rangle - \langle n_f \rangle^2} = \frac{D_{fb}^2}{D_{ff}^2}, \quad (1)$$

where  $n_f$  and  $n_b$  are, respectively, the number of charged particles in forward and backward pseudorapidity bins defined relatively and symmetrically to a given pseudorapidity  $\eta$ . The  $\langle n_f \rangle$  ( $\langle n_b \rangle$ ) is the mean value of  $n_f$  ( $n_b$ ), the  $D_{fb}^2$  and  $D_{ff}^2$  are the forward-backward multiplicity covariance and forward multiplicity variance, respectively. One always studies  $b$  as a function of the center distance of two forward and backward pseudorapidity bins ( $\Delta\eta$ ) and the  $\eta$  acceptance.

## II. THE PACIAE MODEL

The parton and hadron cascade model, PACIAE [19], is based on PYTHIA [21] which is a model for high energy hadron-hadron ( $hh$ ) collisions. The PACIAE model is composed of four stages: parton initialization, parton evolution (rescattering), hadronization, and hadron evolution (rescattering).

1. PARTON INITIALIZATION: In the PACIAE model, a nucleus-nucleus collision is decomposed into the nucleon-nucleon ( $NN$ ) collisions based on the collision geometry. The  $NN$  collision is described with the

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PYTHIA model, i.e. it is decomposed into the parton-parton collisions. The hard parton-parton collision is described by the lowest-leading-order (LO) pQCD parton-parton cross section [22] with modification of parton distribution function in the nucleon. And the soft parton-parton interaction is considered empirically. The semi-hard, between hard and soft, QCD  $2 \rightarrow 2$  processes are also involved in the PYTHIA (PACIAE) model. Because the initial- and final-state QCD radiation added to the parton-parton collision process, the PYTHIA (PACIAE) model generates a partonic multijet event composed of quark pairs, diquark pairs and gluons for a  $NN$  ( $hh$ ) collision. That is followed, in the PYTHIA model, by the string-based fragmentation scheme (Lund string model and/or Independent Fragmentation model). Thus a hadronic final state is reached for a  $NN$  ( $hh$ ) collision. However, in the PACIAE model above fragmentation is switched off temporarily, so the result is a partonic multijet event instead of a hadronic state. If the diquarks (anti-diquarks) are split forcibly into quarks (anti-quarks) randomly, the consequence of a  $NN$  ( $hh$ ) collision, thus a nucleus-nucleus collision, is its initial partonic state composed of quarks, anti-quarks, and gluons.

2. **PARTON EVOLUTION:** The next stage in the PACIAE model is the parton evolution (parton rescattering). Here the  $2 \rightarrow 2$  LO-pQCD differential cross sections [22] are employed. The differential cross section of a subprocess  $ij \rightarrow kl$  reads

$$\frac{d\sigma_{ij \rightarrow kl}}{d\hat{t}} = K \frac{\pi\alpha_s^2}{\hat{s}} \sum_{ij \rightarrow kl}, \quad (2)$$

where the  $K$  factor is introduced for considering the higher order pQCD and non-perturbative QCD corrections as usual and  $\alpha_s$  stands for the effective strong coupling constant. Taking the process  $q_1 q_2 \rightarrow q_1 q_2$  as an example one has

$$\sum_{q_1 q_2 \rightarrow q_1 q_2} = \frac{4}{9} \frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2}, \quad (3)$$

where the  $\hat{s}$ ,  $\hat{t}$ , and  $\hat{u}$  are the Mandelstam variables. Since it diverges at  $\hat{t}=0$ , it has to be regularized by introducing the parton colour screen mass  $\mu$  as follows

$$\sum_{q_1 q_2 \rightarrow q_1 q_2} = \frac{4}{9} \frac{\hat{s}^2 + \hat{u}^2}{(\hat{t} - \mu^2)^2}. \quad (4)$$

The total cross section of the parton collision  $i+j$  then reads

$$\sigma_{ij}(\hat{s}) = \sum_{k,l} \int_{-\hat{s}}^0 d\hat{t} \frac{d\sigma_{ij \rightarrow kl}}{d\hat{t}}. \quad (5)$$

With above total and differential cross sections the parton evolution (parton rescattering) can be simulated by the Monte Carlo method.

3. **HADRONIZATION:** The parton evolution stage is followed by the hadronization at the moment of partonic freeze-out (no more parton collision at all). In the PACIAE model, the phenomenological fragmentation model and coalescence model are supplied for the hadronization of partons after rescattering. The String Fragmentation (SF) model is adopted in this paper. We refer to [19] for the details of the hadronization stage.

4. **HADRON EVOLUTION:** After hadronization the rescattering among produced hadrons is dealt with the usual two-body collision model. We neglect the hadronic rescattering in  $pp$  collisions as usual. The details of hadronic rescattering see [23].

TABLE I: Charged particle multiplicity ( $|\eta| \leq 5.4$ ) in  $pp$  collisions at  $\sqrt{s}=200$  GeV.

	PACIAE		Exp. data <sup>2,3</sup>
	parton <sup>1</sup>	hadron <sup>2</sup>	
no parton scat.	5.96	21.2 (17.7) <sup>4</sup>	
18% parton scat.	6.13	21.7 (18.5)	$19.9 \pm 2.2$
58% parton scat.	6.15	21.9 (18.7)	

<sup>1</sup> after parton rescattering, in full  $\eta$  phase space.

<sup>2</sup> in final hadronic state.

<sup>3</sup> inelastic  $pp$  collision data taken from [24].

<sup>4</sup> value given in bracket is calculated for inelastic  $pp$  collisions.

### III. PARTON RESCATTERING EFFECT ON HADRON MULTIPLICITY CORRELATION

As we aim at the physics behind the experimental data rather than reproducing the data, model parameters are fixed in the calculations. All calculations are for  $\sqrt{s}=200$  GeV Non-Single Diffractive (NSD) collisions except that marked especially. In order to see the parton rescattering effect in the parton evolution stage, we design no, weak, and strong parton rescattering cases as follows:

- No parton rescattering:  $K=0$ , without parton rescattering at all.
- Weak parton rescattering:  $K=1$  and  $\mu^2=0.4$  GeV<sup>2</sup>/c<sup>4</sup>, with nearly 18% charged partons participating the rescattering.
- Strong parton rescattering:  $K=3$  and  $\mu^2=0.1$  GeV<sup>2</sup>/c<sup>4</sup>, with nearly 58% charged partons participating the rescattering.

Table I shows that although we did not adjust the model parameters the PHOBOS multiplicity data of final state charged hadrons[24] are well reproduced. From the PACIAE results in this table one sees that the multiplicity of initial state charged partons ( $u+d+s$  and their anti-particles) and final state charged hadrons increase weakly from no, to weak, and to strong parton rescattering case. This increase in percentage is not as strong

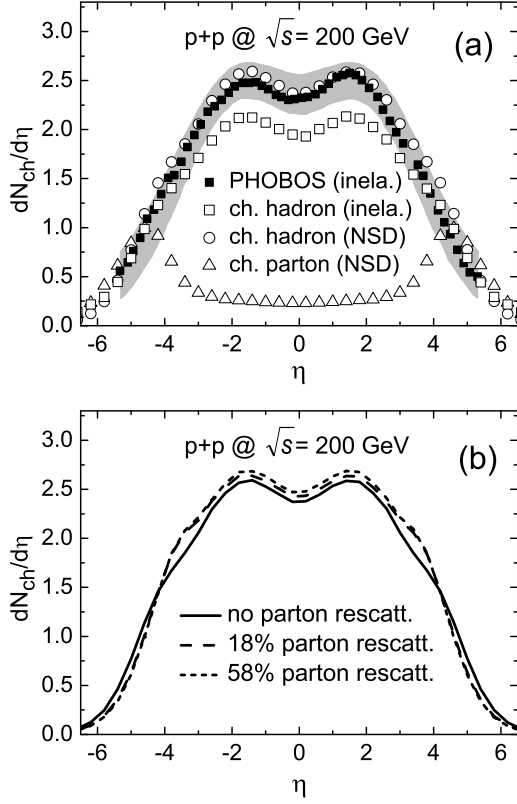


FIG. 1: (a) The pseudorapidity distributions of the initial state charged partons and final state charged hadrons and (b) the parton rescattering effect on the final state charged hadron pseudorapidity distribution in  $pp$  collisions at  $\sqrt{s}=200$  GeV. The PHOBOS inelastic  $\eta$  distribution data are taken from [24].

as the increase in percentage of participating charged parton given in the rescattering case definition. This is because the total number of initial state charged partons is just around 6 and only the  $2 \rightarrow 2$  parton rescattering processes are considered in the parton evolution stage.

The calculated pseudorapidity distributions of initial state charged partons and final state charged hadrons are compared in Fig. 1(a). The full and open squares are, respectively, the PHOBOS inelastic  $pp$  collision data (taken from [24]) and the corresponding theoretical results for final state charged hadrons. And the open circles are theoretical results calculated for final state charged hadrons in NSD  $pp$  collisions. One sees that the PHOBOS data agree well with the NSD calculations but are higher than the inelastic calculations in the center  $\eta$  region. This is consistent with the fact that the charged hadron multiplicity in inelastic calculations is lower than the PHOBOS data as shown in Tab. I. Comparing the  $\eta$  distribution of final state charged hadrons to the one of initial state charged partons (open triangles) we know that the parton rescattering and fragmentation fill up the wide valley between two fragmentation peaks at  $|\eta| \sim 5$

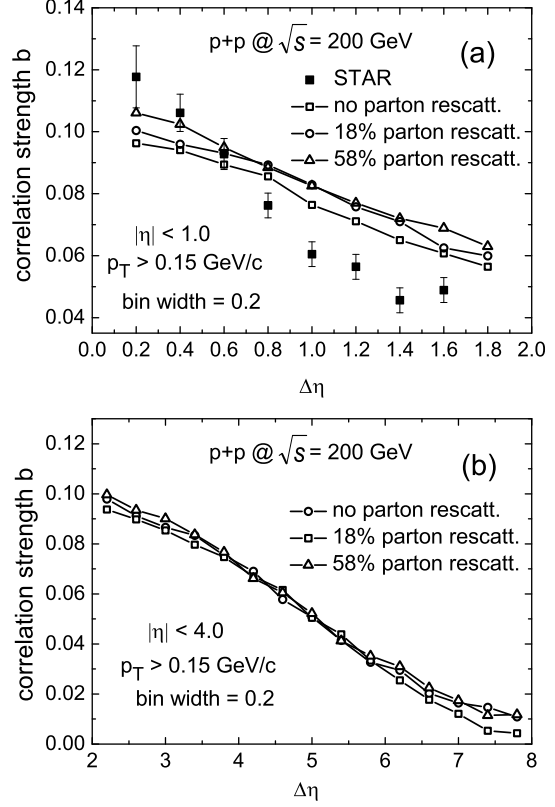


FIG. 2: The parton rescattering effect on the final state charged hadron forward-backward multiplicity correlation strength in (a) central pseudorapidity range ( $|\eta| < 1$ ) and (b) outer pseudorapidity range ( $1 < |\eta| < 4$ ) in  $pp$  collisions at  $\sqrt{s}=200$  GeV. The open squares, open circles and open triangles are for case of no, 18% and 58% participant parton, respectively. The experimental data are taken from [18].

in the  $\eta$  distribution of initial state charged partons.

Fig. 1(b) shows the parton rescattering effect on the pseudorapidity distribution of final state charged hadrons. One sees that in the  $|\eta| \leq 4$  region the pseudorapidity distributions move upward monotonously from no, to weak, and to strong parton rescattering case. However, in the outer region one sees nearly the opposed situation.

Figure 2 shows the parton rescattering effect on the forward-backward multiplicity correlation strength of final state charged hadron in  $pp$  collisions at  $\sqrt{s}=200$  GeV. The corresponding experimental data [18] are given by full squares. We see in panel (a) that the correlation strength increases with increasing strength of parton rescattering in the central pseudorapidity region of  $|\eta| < 1$  (or  $\Delta\eta < 2$ ). While panel (b) shows that the parton rescattering effect becomes weaker in the outer pseudorapidity region  $|\eta| > 1$  (or  $\Delta\eta > 2$ ). It has to point out here that the  $\eta$  acceptance in panel (b) is nearly four times larger than the one in panel (a) so the  $b$  at  $\Delta\eta = 2$

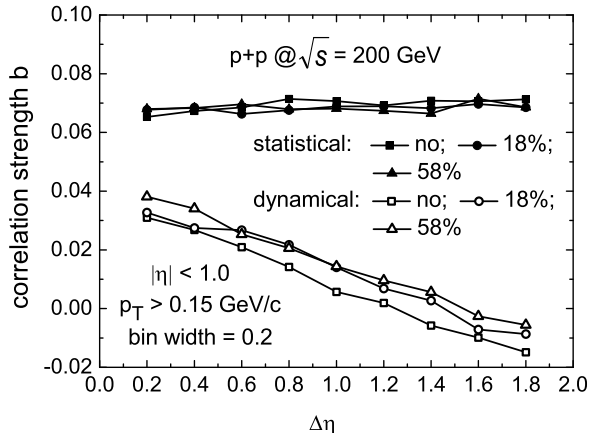


FIG. 3: The parton rescattering effect on the statistical and dynamical correlations of final state charged hadron in central pseudorapidity range ( $|\eta| < 1$ ) in  $pp$  collisions at  $\sqrt{s}=200$  GeV.

in panel (b), for instance, is larger than the corresponding one in panel (a).

We also use the mixed events method [16] to study the parton rescattering effect on the statistical and dynamical (non-statistical) correlations separately. The results are shown in Fig. 3. We see that the initial state parton rescattering have almost no effect on statistical correlations. That is because the statistical correlation is steaming from the multiplicity fluctuation in the detected  $\eta$  bins and the parton rescattering have only little effect on the multiplicity of final state hadrons as shown in Tab. I. However, one sees that the dynamical correlation strength is increasing monotonously from no, to weak, and to strong parton rescattering case in central pseudorapidity range ( $|\eta| < 1$ ). That shows the parton rescattering increase the dynamical correlation among

partons, it survived the hadronization, and effected on the dynamical correlation of final state hadrons.

#### IV. SUMMARY

Using a parton and hadron cascade model PACIAE we have investigated the parton rescattering effect on forward-backward multiplicity correlation strength of the final state charged hadron in  $pp$  collisions at  $\sqrt{s} = 200$  GeV. The calculated multiplicity and pseudorapidity distributions of the final state charged hadron are well compared with the corresponding experimental data. It turned out that the pseudorapidity distribution of final state charged hadron is different from the initial state charged parton. The parton rescattering effect on the forward-backward multiplicity correlation of the final state charged hadron increases with increasing parton rescattering strength in the center pseudorapidity region ( $|\eta| < 1$ ). This increase becomes weaker in the outer pseudorapidity region ( $|\eta| > 1$ ). However, the final state hadron correlation strength is related to the initial state partons.

The parton rescattering effect on the forward-backward multiplicity correlation of final state charged hadron is not as strong as expected from the increasing of participating charged parton. That is because the average total number of initial state charged partons is just around 6 in above collisions and the parton rescatterings considered in parton evolution stage are all  $2 \rightarrow 2$  processes. This is consistent with the notion that the small probability of QGP formation in  $pp$  collisions at RHIC. One may expect much stronger parton rescattering effect in the nucleus-nucleus collisions at the same energy and even in the  $pp$  collisions at LHC energy.

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